BAKER BOTTS L.L.P.

30 ROCKEFELLER PLAZA

NEW YORK, NEW YORK 10112-4498

TO ALL WHOM IT MAY CONCERN:

Be it known that WE, GUILLERMO J. TEARNEY, a citizen of the United States, residing in the United States, County of Middlesex, State of Massachusetts, whose post office address is 118 Kinnaird Street #3, Cambridge, Massachusetts 02139; MILEN STEFANOV SHISHKOV, a citizen of the Bulgaria, residing in the United States, County of Middlesex, State of Massachusetts, whose post office address is 131 Coolidge Av. apt. 516, Watertown, MA 02472; NICURSOR IFTIMIA, a citizen of the Rumania, residing in the United States, County of Providence, State of Rhode Island, whose post office address is 102 Cobble Hill Road, Lincoln, RI 02865; BRETT E. BOUMA, citizen of the United States, residing in the United States, County of Norfolk, State of Massachusetts, whose post office address is 12 Monmouth Street, Quincy, Massachusetts 02114; and MARTHA PITMAN, a citizen of the United States, residing in the United States, County of Essex, State of Massachusetts, whose post office address is 23 Nason Road, Swampscott, Massachusetts 01907, have invented an improvement in

SYSTEM AND METHOD FOR IDENTIFYING TISSUE USING LOW-COHERENCE INTERFEROMETRY

of which the following is a

SPECIFICATION

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Serial Number 60/442,392 filed January 24, 2003, entitled "Devices and Methods for Tissue Identification Using Low-Coherence Interferometry," which is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to an apparatus and method for identifying tissue types using interferometric ranging during needle biopsy. More particularly, the present invention relates to an imaging system including a needle probe and algorithms for detecting various tissue types during a biopsy. Also provided is a method for differentiating tissue types using the imaging system.

Background of the Invention

[0003] A significant cause of inefficiency of intraoperative and biopsy procedures is the inability of a physician to identify tissue type by gross inspection. For example, head and neck surgeries, the inability to differentiate muscle, fat, lymph node, and parathyroid glands by gross inspection leads to unnecessary operative time, resulting in an increase in the cost of these procedures. Further, when not guided by an imaging modality, fine needle aspiration biopsies yield non-diagnostic tissue in 25% to 35% of cases. In medicine, there is a significant need for an inexpensive, portable, and efficient way for identifying tissue type.

[0004] The use of optical coherence tomography and confocal microscopy in needle probes has been previously described. These needle probes allow physicians to acquire images of tissue. However, these conventional needle probes have certain shortcomings. The methods used in these needle probes require imaging a single focused spot on a sample by scanning the spot in two dimensions in order to produce a two dimensional image of the subject. The scanning and imaging requirements of these known imaging needle probe systems require complex and expensive disposable components, as well as console components. Many components of existing imaging needle probes require complex and expensive construction making routine use of the needle probes

a practical impossibility. Further, current imaging needle probes use complex and expensive custom syringes, which may not be sterilizable or disposable.

[0005] In the past, research has been performed to evaluate the use of low-coherence interferometry ("LCI") imaging for tissue diagnosis. Optical coherence tomography ("OCT") is LCI imaging that is performed by obtaining many axial scans while scanning a sample arm beam across a specimen, creating a two dimensional image. In order to perform LCI imaging, several strict requirements must be met by the conventional systems, including use of:

1. high speed reference arm delay scanning (at least 1,000 scans/second),
2. a high power broad bandwidth source (at least 5 mW),
3. a complex probe (must have at least one lens and a scanning mechanism),
4. an expensive data acquisition apparatus, and
5. an image display.

These requirements of the conventional systems dramatically increase the cost of OCT systems and OCT probes.

[0006] It would be desirable to have a low cost and accurate imaging system, process and needle biopsy probe having sufficient resolution that can be used by physicians with little additional training. It would also be desirable to have a needle biopsy probe that would use conventional syringe and needle combinations to avoid the high cost of developing and manufacturing custom barrels or needles. Such an exemplary system would also desirably be able to provide real time, or

near real time, feedback regarding progress and location of the biopsy needle. Such a probe should also be able to identify various tissue types and interfaces and be able to alert a user when a target site has been reached or if an inappropriate tissue has been encountered. Interfaces are refractive index interfaces which occur when one tissue having optical refractive index is adjacent to another. The refractive index is unique to the molecular constituents of tissue and therefore interfaces occur throughout tissue. These refractive index interfaces may give rise to scattering which is the signal detected by LCI and OCT.

[0007] Other features and advantages of the present invention will become apparent upon reading the following detailed description of embodiments of the invention, when taken in conjunction with the appended claims.

SUMMARY OF THE INVENTION

[0008] The present invention generally provides devices, processes, software arrangements and storage media for identifying tissue types using interferometric ranging. The probe or disposable portion of the device uses a solitary single mode optical fiber, which is inexpensive and may fit into the lumen of a clinically available needle. The solitary single mode optical fiber can be between 125 μm and 250 μm in diameter.

[0009] According to the present invention, two dimensional imaging is not required. As a result, the requirements of the imaging system are significantly reduced. Such requirements include, but are not limited to the use of:

1. a low power broad bandwidth source (.001-.5 mW),
2. a simple probe (does not require a lens or scanning mechanism),

3. an inexpensive data acquisition apparatus,

4. a simple, inexpensive and small detector apparatus, and

5. a simplified image display or audible notification apparatus.

[0010] Accordingly, the system that uses one-dimensional interferometric ranging to identify tissue according to the present invention allows for a decreased cost and size of the system console and a significantly decreased cost of the disposable data collection probe. Disposable probes according to the present invention may be constructed with material cost far below that of existing systems, and the light source and detection devices required also cost significantly less than those of conventional OCT systems. These considerations could allow these probes to be used in very common procedures, such as placing an intravenous catheter or guiding a lumbar puncture. Further, due to the cost savings and reduced size of the system components, the present invention may be implemented in a hand-held unit.

[0011] Other features and advantages of the present invention will become apparent upon reading the following detailed description of embodiments of the invention, when taken in conjunction with the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Further objects, features and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying figures showing illustrative embodiments of the invention, in which:

[0013] Fig. 1A is a graph of LCI reflectivity for muscle tissue.

[0014] Fig. 1B is a graph of LCI reflectivity for adipose tissue.

[0015] Fig. 2 is a schematic view of a tissue identification system according to one exemplary embodiment of the present invention.

[0016] Figs. 3A-C are area schematic views of different fiber and probe designs according to one exemplary embodiment of the present invention.

[0017] Fig. 4 is a schematic view of an interferometric ranging probe in the lumen of a biopsy needle according to one exemplary embodiment of the present invention.

[0018] Fig. 5 is a schematic view of a syringe interferometric ranging probe with a single mode fiber inserted through the body of the syringe according to one exemplary embodiment of the present invention.

[0019] Fig. 6 is a schematic view of a syringe interferometric ranging probe with a single mode fiber inserted through the plunger of the syringe according to one exemplary embodiment of the present invention.

[0020] Fig. 7 is a schematic view of a syringe interferometric ranging probe with a single mode fiber inserted through an intermediate adapter between the syringe needle lock and the needle housing according to one exemplary embodiment of the present invention.

[0021] Fig. 8 is a schematic view of a syringe interferometric ranging probe with a single mode fiber inserted through an adapter between the syringe needle lock and the needle housing and includes a motion transducer according to one exemplary embodiment of the present invention.

[0022] Fig. 9 is a schematic view of a needle biopsy apparatus with an activation gun according to one exemplary embodiment of the present invention.

[0023] Fig. 10 is a schematic view of a cannula with an interferometric ranging probe in the body according to one exemplary embodiment of the present invention.

[0024] Fig. 11 is a schematic view of a cannula with an interferometric ranging probe in the lumen according to one exemplary embodiment of the present invention.

[0025] Fig. 12 is a schematic view of a cannula with an interferometric ranging probe in an electrocautery device according to one exemplary embodiment of the present invention.

[0026] Fig. 13A is a schematic view of a standard needle and housing.

[0027] Fig. 13B is a schematic view of a standard needle and a modified housing according to one exemplary embodiment of the present invention.

[0028] Fig. 14 is a schematic view of an interferometric ranging probe optical connector according to one exemplary embodiment of the present invention.

[0029] Fig. 15 is a schematic view of a biopsy probe with an associated feedback unit according to one exemplary embodiment of the present invention.

[0030] Fig. 16 is a schematic detail view of a gun and activation button according to one exemplary embodiment of the present invention.

[0031] Fig. 17 is a flow diagram of a method for tissue identification according to one exemplary embodiment of the present invention.

[0032] Fig. 18 is a schematic view of a system configuration according to one exemplary embodiment of the present invention.

[0033] Fig. 19 is a flow diagram of a signal processing sequence according to one exemplary embodiment of the present invention.

[0034] Throughout the figures, the same reference numerals and characters, unless otherwise stated, are used to denote like features, elements, components or portions of the illustrated embodiments. Moreover, while the subject invention will now be described in detail with reference to the figures, it is done so in connection with the illustrative embodiments. It is intended that changes and modifications can be made to the described embodiments without departing from the true scope and spirit of the subject invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

[0035] In accordance with the system of the present invention, Fig. 2 illustrates an tissue identification system 2 according to one embodiment of the present invention for tissue 10 identification using interferometric ranging. The tissue identification system 2 utilizes a one-dimensional data set in order to identify tissue. Unlike many prior art systems, which use two-dimensional data in order to acquire sufficient information to identify tissue, the tissue identification system 2 is able to identify tissue using a one-dimensional data set. Differences between two types of tissue may be understood from a one-dimensional data set. For example, Fig. 1 illustrates two graphs that represent a one-dimensional interferometric ranging axial scan of two different tissue types. As can be seen from these graphs, adipose tissue (shown in the bottom graph) has a significantly different axial reflectance profile as compared to the axial reflectance profile of muscle

tissue (shown in the top graph). The tissue identification system 5 includes an imaging system 5 and a probe 50.

[0036] The imaging system 5 includes a light source 12, which is provided in an interferometer 14. The interferometer 14 can be a fiber optic interferometer 14. Also, while light is used in the disclosure herein as an exemplary embodiment of the light source 12, it should be understood that other appropriate electromagnetic radiation can be used, such as, microwave, radio frequency, x-ray, and the like. The interferometer 14 or other beam splitting device known to those skilled in the art may make use of circulators for increased sample arm power efficiency. The interferometer 14 includes a beam splitter 18, a reference arm 20, a sample arm 24, and a communications link to at least one detector 26. The light source 12 is connected to the interferometer 14 such that the light emitted from the light source 12 is transmitted to the beam splitter 18. The beam splitter 18 directs portion of the light emitted by the source 12 towards a reference arm 20, while the remainder of light is directed to a sample arm 24. The reference arm 20 includes a mechanism 26. The mechanism 26 produces a time dependent optical delay. In a certain embodiment, the mechanism 26 can be a movable reference reflector or mirror. The movable reference reflector or mirror can create a variable time delay suitable for a specific application.

[0037] An optical fiber 29, associated with the sample arm 24, is connected to an optical coupler 58. The optical coupler 58 is also connected to an optical fiber 25, which is inserted into the probe 50, as described below. The light signals returned from the sample arm 24 and the reference arm 20 are combined by the beam splitter 18 and reflectivity as a function of depth within the tissue sample 10 (e.g., see Figs. 1A and 1B) is determined by measuring the interference between the two arms with at least one detector 26. Detection of a tissue birefringence (i.e., by splitting a ray into two

parallel rays polarized perpendicularly) can be accomplished by using, e.g., two detectors 26, one for each polarization eigenstate. Depending on the type of interferometric ranging used, one to four detectors 26 may be employed.

[0038] In a certain embodiment, one of three types of interferometric ranging can be used: (i) optical time domain reflectrometry, (ii) spectral domain reflectrometry or (iii) optical frequency domain reflectrometry. It should be understood that additional alternate types of interferometric ranging could be used with the tissue identification system 2. If optical time domain reflectometry is utilized, the source 12 can be is a broad bandwidth light source, the interferometer 14 is needed, the reference arm 20 may be a low speed reference arm with delay scanning performing 20 to 50 scans per second, and the detector 26 can include one to four detectors. Optical time domain reflectometry is described in more detail by C. Youngquist et al., "Optical Coherence-Domain Reflectometry: A New Optical Evaluation Technique", Opt. Lett., 12, 158-160 (1987), and K. Takada et al., "New Measurement System For Fault Location in Optical Waveguide Devices Based on an Interferometric Technique", Appl. Opt. 26, 1603-1606 (1987), the entire disclosure of which are incorporated herein by reference. If spectral domain reflectometry is used, the source 12 is a broad bandwidth light source, the interferometer 14 is required, the detection arm includes a spectrometer, the detector 26 includes a single detector, and low coherence interferometry data is obtained by taking the Fourier transform of the measured spectrum. Spectral domain reflectometry is described in more detail by J. Deboer et al., "Improved Signal to Noise Ratio In Spectral Domain Compared With Time Domain Optical Coherence Tomography", Optics Letters 2003, vol. 28, p. 2067 - 69; and Published Patent No. WO 03062802, entitled "Apparatus and Method for Ranging and Noise Reduction of Low Coherence Interferometry (LCI) and Optical Coherence Tomography

(OCT) Signals by Parallel Detection of Spectral Bands", to Deboer et al., the entire disclosure of both of which are incorporated herein. If optical frequency domain reflectometry is used, the source 12 is a swept wavelength optical source, the interferometer 14 is required, the detector 26 includes one to four detectors, and low coherence interferometry data is obtained by taking the Fourier transform of the measured spectrum. Optical frequency domain reflectometry is described in more detail by S. Yun et al., "High Speed Optical Frequency Domain Imaging", Optics Express 2003, vol. 11, p. 2953 - 63, and C. Youngquist et al., "Optical Coherence-Domain Reflectometry: A New Optical Evaluation Technique, Opt. Lett., 12, 158-160 (1987), and K. Takada et al., "New Measurement System For Fault Location In Optical Waveguide Devices Based on an Interferometric Technique", Appl. Opt. 26, 1603-1606 (1987), the entire disclosure of both of which are incorporated herein.

[0039] In an alternate embodiment of the present invention, the interferometer 14 is a Mach-Zehinder interferometer, a Michelson interferometer, a non-reciprocal or circular interferometer, a Sagnac interferometer, a Twyman-Green interferometer and the like. In another alternate embodiment of the present invention, the interferometer 14 is an interferometer as described in U.S. Provisional Application Serial Number 60/514,769 filed October 27, 2003, entitled “Apparatus and Method from Performing Optical Imaging Using Frequency-Domain Interferometry,” the disclosure of which is incorporated herein by reference in its entirety.

[0040] A probe 50 can include a biopsy device 51, which includes a needle 52 having a bore (not shown) associated with a syringe 54 through which the optical fiber 25 is introduced. The fiber 25 may be inserted into the probe 50 and in turn into the needle 52. The needle 52 and fiber 25 can be inserted percutaneously (or otherwise) toward the tissue 10 to be sampled. In other exemplary

embodiments, the needle 52 can be a generic barrel, a specialized barrel, a needle, a stylet, and the like.

[0041] Referring now to Fig. 3, the fiber 25 includes a cladding 60 and a cleaved anoptical fiber core 62, as shown in portion A of Fig. 3. When light signal is directed through the fiber 25 it forms a beam waist 64. The beam waist may be about 9 μm in diameter. Other lenses or optical elements may be attached to the fiber 25 to allow for focusing deeper into tissue, including a gradient index lens 66 (see portion B of Fig. 3), sometimes referred to as a GRIN lens, a ball lens 68 (see portion C of Fig. 3), a drum lens, a microlens, a tapered fiber end, a prism and the like. Alternatively, the fiber 25 may be angle cleaved or otherwise configured to produce an arbitrary pattern of electromagnetic radiation. In a certain embodiment, the cladding 60 has an outer diameter of 125 μm and the anoptical fiber core has an outer diameter of 9 μm.

[0042] For needle biopsies that are traditionally performed using computerized tomography (CT), magnetic resonance imaging (MRI), or ultrasound guidance, the fiber 25 may be inserted into the biopsy needle 52 as shown in Fig. 4 and may be embedded within the needle biopsy device, or inserted through the lumen 70 of the needle 52. These types of procedures do not use fine needle aspiration. The lump or mass is not manually identifiable, but can only be identified through some other non-invasive imaging technique, such as CT or MRI. These and other guided needle biopsy procedures may use a larger and longer needle, while still utilizing the fiber 25 to assist in guiding the biopsy procedure.

[0043] To insert the fiber 25 into the needle 52 of the probe 50 for fine needle aspiration, the fiber 25 may be inserted through an aperture 72, wherein Figure 5 does not shown the aperture 72 in the

body, in the body of the syringe 51 and then (i) into the needle 52 as shown in Fig. 5, (ii) through the plunger 74 of the syringe 51, and then provided into the needle 52 as shown in Fig. 6, (iii) through an intermediate piece 76 that is attached between the syringe 51 and the needle 52 as shown in Fig. 7, and/or by other insertion configurations. The probe 50 can be configured to allow suction for the aspiration of cells from the tissue 10, while allowing free movement of the fiber 25 at the tip of the needle 52.

[0044] In an exemplary embodiment, as shown in Fig. 8, the use of an intermediate coupler or holder between the syringe and the needle can be utilized. This would allow the use of standard needles and syringes. In this exemplary embodiment, a probe 100 utilizes the imaging system 5 as described above to identify tissue. The probe 100 includes an input fiber 102 attached to the imaging system 5 at one end, and to an optical connector 58 at the other end. The optical fiber 102 is connected to a single mode input fiber 104. The optical fiber 102 is inserted through an intermediate adapter 106, located between a syringe 108 and a needle lock 110. A needle 112 is attached to the needle lock 110. A motion transducer 114 may be used as a result of too little space between the outer surface of the fiber 104 and the inner bore surface of the needle 112. The motion transducer 114 generally allows the fiber 104 to be repositioned in order to allow aspiration of the tissue 10. The motion transducer 114 can be a manual motion transducer, an automated motion transducer, or the like. In another exemplary embodiment of the present invention, the needle lock 110 is a Luer lock.

[0045] Fig. 9 illustrates a tissue identification system 122 that includes the syringe 108 held within a device known in the art as a gun 120. This configuration allows for easy aspiration of the

tissue 10 into the bore of the needle 112. Many of the components described above can also be incorporated into the tissue identification system 122 for easy access and convenience.

[0046] Fig. 10 illustrates an exemplary operation of placing a cannula 200 for IV access, pleural, perioneal taps, and the like according to a further embodiment of the present invention. The cannula 200 includes a guide catheter 202 and a fiber optic probe 204. The fiber optic probe 204 is provided within the guide catheter 202. Alternatively, the probe 204 may be inserted through the lumen 206 of the guide catheter 202 as shown in Fig. 11.

[0047] Fig. 12 illustrates an intra-operative exemplary embodiment 300 of a probe 306 according to still another embodiment of the present invention. The probe 306 is incorporated into an electrocautery device 301. An optical window 302 may be placed near the distal fiber tip 304 to protect the probe 306 against thermal damage by the cautery electrode 308. In yet another embodiment, the probe 306 may be incorporated into a scalpel, an independent hand-held device and the like instead of being incorporated into the electrocautery device 301. The optical window 302 can be made of sapphire.

[0048] In order to allow for easy insertion of the fiber optic probe 25 into the needle 52, the internal lumen 400 of a standard needle housing 402, as shown in section A of Fig. 13, can be modified such that the internal lumen 404 of a modified needle 406 is tapered, as shown in Fig. 13B.

[0049] Fig. 14 illustrates an interferometric ranging probe optical connector 500, which is one side of the optical coupling 58, which can be used according to the present invention. The optical coupling 58, which connects the probe 50 to the imaging system 5, should be robust and simple to

use. In another embodiment, the optical coupling 58 includes a bare fiber connector attached to the probe 50, which is relatively inexpensive, and the interferometric ranging probe optical connector 500 attached to the imaging system 5, which is relatively expensive. The use of a bare fiber connector attached to the probe 50 does not increase the cost of the probe 50. The more expensive portion of the optical coupling 58 is attached to the imaging system 5. The interferometric ranging probe optical connector 500 is constructed so as to engage with a bare fiber connector, such that a robust connection is made. The interferometric ranging probe optical connector 500 may include a cleaved (angle cleaved) fiber 502 (the proximate end of which is connected to the imaging system 5, not shown for the sake of clarity) inserted through a housing 504 having a ferrule 506 connected to a tapered v-groove 508. The tapered v-groove 508 is terminated by a fiber stop 510. The housing 504 has a taper 516 at one end through which a fiber 518 is inserted. The fiber 518 is inserted into the housing 504 via the taper 516 until it reaches the fiber stop 510. Once the fiber 518 comes to a stop, a clamp 512 holds the fiber 518 in place, away from the fiber-fiber interface, such that an air or fluid gap 514 is maintained. The fiber 518 is connected to the probe 50. In another embodiment, coupling gel may be used with flat cleaves to eliminate back-reflection from the gap 514.

[0050] A number of optional mechanisms or apparatus configured to communicate specific information to a user regarding the tissue 10 being encountered by the tissue identification system 2 during a procedure may be used. Fig. 15 illustrates a schematic diagram of a system 600 with components of an imaging system 5 and the optical fiber 29 connected to the fiber 25 via the optical connector 58. The fiber 25 is operatively associated with a syringe 51 and passes through the bore of a needle 52. A holder 612 is associated with the syringe 51 by the syringe barrel 614. A feedback unit 620 can be associated with the holder 612 in any of several ways.

[0051] The holder 612 can be attached to the syringe 51. In an exemplary embodiment, the holder 612 is removably attachable to the syringe 51, such as, but not limited to, snap fit, removable adhesive, clamping, clipping or the like. By having the holder 612 be removably attachable to the syringe 51, the holder 612 and associated feedback unit 620 can be reused while the syringe 608 can be disposable, thereby enabling conventional syringes to be used and eliminating the need for a custom developed and expensive probes.

[0052] In another embodiment, the holder 612 is removably attachable to the syringe 51 using a gun or syringe holder. In another certain embodiment, the system 600 is integrally related to the gun (described above in relation to Fig. 9). In still another embodiment, the system 600 is embedded within the gun 634, which holds the feedback unit 620 and fiber 606 and improves the ability of the physician to aspirate tissue into the needle 610.

[0053] The feedback unit 620 provides information to the user of the system 600, including that the system 600 has detected tissue of a particular type. In another embodiment, the feedback unit 620 is a visual display, such as, LED, VGA, or other visual feedback system. With an LED display, the software algorithm and tissue identification determinations, as described hereinbelow, can use an output signal to drive one or more LEDs, which can be actuated when the probe tip passes through or in proximity to differing tissue interface types (e.g., adipose versus muscle). As the tip contacts tissue of interest, such as a masticular lump, an LED light can change color or a different colored LED can be actuated to provide the physician feedback that the lump has been contacted and that the biopsy aspiration or other sampling can commence.

[0054] In still another embodiment of the present invention, the feedback unit 620 is an audible tone generator, which provides audio feedback as different tissue or other structures are detected by the system 600. In a further embodiment, the feedback unit 620 is a vibration generator. Each of the visual, audio and vibration feedback units provide simple and yet useful feedback to users of the system 600 to better target a biopsy probe in real time and with confidence. In yet another embodiment, the feedback unit 620 is a visual display screen that can be used to display a one or two-dimensional rolling plot image, comprising accumulated backscattered intensity as a function of z or depth within tissue, i.e. I_z, over time to form an image. The visual display can be a conventional CRT display or an LCD display for providing more detailed or multimodal feedback. The visual display can be as small as or smaller than a conventional cell phone display or large to afford the user of the system 600 with a magnified view of the tissue 10.

[0055] The feedback unit 620 is communicatively coupled to the imaging system 602 by a physical cable connection 622 or via a wireless connection. The wireless connection can be a radio frequency ("RF") connection, electromagnetic radiation signal, or the like. A wireless signal connection allows for reduced weight of the biopsy probe and fewer wires in the surgical site. A simple feedback system can be utilized so that the physician can operate the biopsy probe with one hand and have feedback proximate to the probe body so that the physician's concentration and visual focus does not leave the biopsy area.

[0056] Fig. 16 illustrates a further embodiment of the feedback unit 620 including a display 630, a manually operated button or switch 632 and a gun 634. The switch 632 is operatively connected to the display 630. The actuation of the switch 632 causes the display 630 to show selection of standard biopsy procedures, such as, but not limited to, biopsy of breast tissue, liver tissue, spleen

tissue, muscle tissue, lymph tissue, kidney tissue, prostate tissue and the like. Each of these biopsy procedures involves the probe 50 passing through relatively consistent types of layers, including skin, muscle, fascia, and the like, in a similar order for a given procedure. For example, for a lumbar puncture, the order of layers the probe 50 would encounter are skin fascia, vertebrae, muscle, fascia, disk, subdural space, epidural space, the spinal cord fluid area. Each of these tissues can produce a relatively consistent and determinable imaging signal peak which, when normalized over a substantial patient base by comparative image analysis and subtracting the curves of normalized data versus actual patient data, offers an accurate picture of what will be encountered during the biopsy procedure.

[0057] As the needle tip passes through each layer, the imaging system 600 detects the actual signal, and compares it to reference signals stored in a database. By taking an interferometric ranging scan of, for example, z (shown in Fig. 1) to obtain I(z), and taking the derivative dI/dz over time, a series of lines corresponding to the peaks of the sample may be obtained. The various consecutive peaks can be displayed by the feedback unit 620 to provide the user with accurate feedback of where the probe is and to assist the user in guiding the probe to the target area. The feedback unit can also incorporate an "anti-algorithm" to provide immediate feedback if the probe has wandered, overshot the target site or encountered a tissue type not expected to be detected during a particular procedure, such as, in the example of lumbar puncture, if the probe has passed the target area and hit a nerve. Such feedback can enable the physician to relocate the probe tip to the appropriate area.

[0058] The system and process according to the present invention is also able to determine when a target site has been reached. In order to determine when a target site has been reached, the system

processes data from the reflected light to look for backscattering signatures that are indicative of a tissue type within the target site during a given procedure. Such processing consists of feature extraction and inserting these features into a model that predicts tissue type. This model can be a physical model, a chemometric model, or a combination of the two. A physical model generally predicts the scattering signal based on physical principles of light scattering. A chemometric model uses a training set and statistically extracts features using techniques such as Partial Least Squares ("PLS") or Principle Component Analysis ("PCA"). Such model is developed based on known samples, and the new data can be tested using this model. It should also be understood that fringes may be acquired and processed to determine other tissue features including birefringence, Doppler flow, and spectral characteristics.

[0059] Tissue identification can be accomplished by visualizing the intensity, birefringence, Doppler, spectroscopic axial reflectivity profile and/or the like. Additionally, the frequency spectrum (Fourier transform of the intensity data) of the reflectivity scan will provide information relating to the spacing of the scattering structures in the tissue which relates to tissue structure. A more sophisticated analysis, including, but not limited to, variance analysis, one-dimensional texture discrimination (including fractal dimension, spatial gray level co-occurrence matrix parameters, Markovian distance, edge counting), power spectral analysis (including Fourier domain and time domain), n^{th} order histogram moment analysis, and temporal analysis of the reflectivity information (comparing one scan to another separated by a fixed time) using correlation techniques will provide information relating to the type of tissue observed. Other key quantitative metrics that may be used to characterize tissue types include, measurement of the backscattering coefficient, total attenuation coefficient, estimation of the anisotropy coefficient (particle size) from the onset of multiple

scattering, particle shape and size from the detected spectrum using coherence-gated light scattering spectroscopy, and the like.

[0060] The following illustrative list of tissue characteristics may be found using the system and process of the present invention: adipose tissue, muscle tissue, collagen, nerve tissue, lymph node tissue, necrosis tissue, blood, glandular tissue and the like. Adipose tissue exhibits low absorbance at water peaks, high low spatial frequency components from the LCI intensity image and a high anisotropy coefficient. Muscle tissue exhibits high absorbance at water peaks, moderate birefringence, moderate anisotropy and decreased variance. Collagen exhibits very high birefringence. Nerve tissue exhibits moderate to high birefringence, high water absorbance and decreased power spectral density. Lymph node tissue exhibits a low anisotropy coefficient and a low temporal variance. Necrotic tissue exhibits high temporal variance of LCI signal, high attenuation coefficient, high water absorbance and low birefringence. Blood exhibits high Doppler shift, high water absorbance, high total attenuation coefficient, and high temporal variance. Glandular tissue exhibits moderate spatial frequency variance and low birefringence. It should be understood that the present invention contemplates the use of more than one analysis method, i.e., a multimodal system. This may provide enhanced detection and analysis of tissue types.

[0061] Fig. 17 illustrates a process 700 for differentiating fat tissue from fibrous tissue according to an exemplary embodiment of the present invention. The signal measured by the system 600 is an average of a number M axial scans. The system 600 detects the tissue sample surface using a signal threshold T1 at block 702. The detected signal is divided into N number of windows at block 704. Signal processing is conducted at block 706 to obtain a parameter derived from the interferometric ranging signal, such as the average deviation (ADEV) or standard deviation (STDEV) of the signal

in each window (such as, but not limited to, the technique described in "Numerical Recipes in C", Press, W. et al., Cambridge University Press, New York, NY 1992, the entire disclosure of which is incorporated herein by reference) is calculated. Each window tested to determine if the threshold T2 is exceeded to obtain the tissue type as a function of depth z at block 708. If, at block 710, the system 600 determines that ADEV (or STDEV) is greater than the threshold T2, the tissue is considered to be lipid, and the process 700 advances to block 712. Otherwise, the tissue is not likely to be lipid and the process 700 advances to block 714.

[0062] Applications of this technology can include tissue identification for the purpose of intraoperative guidance, needle biopsy guidance, fine needle aspiration, image guided biopsy, guiding placement of peripheral or central intravenous or intra-arterial catheters, and the like. Different methods of imaging can be used for different applications. These different applications include: guided biopsy; cell methodology; veni-arterio, pattern or Doppler recognition; lumbar, pattern; therapy guidance, pattern and optical methods; and the like. The probe 50 can also be used as a targeting and delivery device for therapeutics. The probe 50 can image the target area to make sure that needle injection of a therapeutic has reached and/or entered the target tissue or site by detecting the tissue type and interface change, i.e. a change in the refractive index of the tissue.

[0063] In order to determine whether the tissue is fibrous tissue or fat tissue, the process 700 utilizes standard image processing techniques to process data in order to differentiate fibrous (adipose) and fat tissue. Table 1, below, illustrates different measurements of fibrous and adipose tissue following the image processing of the data:

TISSUE TYPE	SENS	SPECIFICITY
Fibrous	.95	.98
Adipose	.97	.94
Fibrous/Adipose	.96	.84

In the table above, sensitivity is true positive, i.e. true positive + false negative, while specificity is true negative, i.e. true negative + false positive.

[0064] Fig. 18 illustrates an interferometric ranging diagnostic system 800 for identifying tissue according to the present invention. The system 800 uses a light source configured to emit light having a optical wavelength of 1.3 microns, 300 microwatts power and a 48 nm bandwidth. The light source allows the system 800 to interrogate tissue with a 15 micron resolution. The system 800 utilizes a low scanning frequency of the reference arm because building a coherent image is not the purpose of the system 800. Information can be gathered to identify the tissue through an average of several A-scans. The A-scan can be performed by one sweep of the reference arm, which corresponds to one depth scan. The system 800 processes and stores digital data, and the tissue type information is displayed on the feedback device in real time.

[0065] The LED source of the system 800 is a 300 microwatts SUPERLUM LED, which can be temperature and current controlled. The light is linearly polarized using a fiber optic polarizer P and sent to a beam splitter. The sample is interrogated with two orthogonally polarized states of the light in order to get birefringence information. The two orthogonally polarized states of the light are created by passing the light through the beam splitter, to two polarization controller PC paddles, one in each arm of the beam splitter. The two orthogonal polarization states are sent alternatively to the

fiber optic circulator CIR, which directs the light to the fiber optic Michelson interferometer IF. The optical switch OSW is synchronized with the optical delay line ODL galvanometer, so that the polarization would change alternatively from one scan to the other. A very simple delay line, consisting in a retroreflector mounted to an lever driven by a galvanometer, was used to do the depth scanning. The probe attached to the sample arm of the interferometer IF includes a bare fiber introduced into a syringe needle. The backscattered light is coherently added to the light coming from the ODL and sent to the detectors D1, D2. A polarization splitter PS is used to select the two orthogonal states. The output signals of the detectors are preamplified and digitized using a NI DAQ card.

[0066] The system performs the digital acquisition, filtering, and averaging of the fringes, and provides the following information: (1) depth intensity at 15 microns resolution and spectral information, (2) birefringence information: computes stokes parameters-IQUV and extracts phase retardation, and (3) Doppler shift information.

[0067] Fig. 19 illustrates a flow diagram 900 of the signal processing sequence according to an exemplary embodiment of the present invention. The simplest form of tissue identification is differentiation of two tissue types. The difference between two tissue types can be seen in Fig. 1, which shows the results of a feasibility study to distinguish cadaver fat from fibrous tissue. For example, adipose tissue has an appearance of multiple peaks separated by low interferometric ranging signal segments, whereas fibrous tissue has a lower degree of variance and decays exponentially.

[0068] Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims. It should further be noted that any patents, applications or publications referred to herein are incorporated by reference in their entirety.